

NASA TECHNICAL NOTE



NASA TN D-4861

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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COMPARISON OF INFORMATION DISPLAY CONCEPTS FOR LANDING OF VTOL AIRCRAFT

By William Gracey
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SUMMARY

A variety of instrument displays for the landing of VTOL aircraft are described. The displays are classified in terms of basic concepts for the presentation of attitude and guidance information. The concepts range from the simple display of vertical- and horizontal-situation information to the more complex combination of attitude and guidance information in perspective form. The information elements of the displays are presented either in abstract form or with varying degrees of realism. Guidance information is combined as flight-director commands in some displays and as pictorial presentations in others.

Tests of those displays that have been evaluated either in simulators or in flight are discussed. The review of these tests shows that the only display with which VTOL landings have been achieved in flight (under simulated zero-zero conditions) is the "real-world" display of a closed-circuit television system. A televised display of a simulated real-world landing site is therefore suggested as a possible form of display for achieving VTOL landings under zero-zero conditions.

INTRODUCTION

For manual landings under zero-zero conditions, the instrument display requirements for VTOL aircraft may be more severe than those for STOL and CTOL aircraft because of differences in the requirements for speed control and guidance in the final phase of the approach. In VTOL landings, the pilot must vary the speed in a precise manner to bring the aircraft to a stop over a prescribed position on the ground; he must then execute a descent to touchdown at essentially zero speed. The instrument display, therefore, must present the ground speed and guidance information with sufficient accuracy and in such a form that the pilot will be able to perform the deceleration-to-hover and descent-to-touchdown with a high degree of precision. In addition, since the attitude and position of the aircraft can change rapidly and continuously during the final phase of the approach (because of the effects of winds and the inherent instability of VTOL aircraft at very low

speeds), there is an additional requirement that the attitude and guidance information be presented in a form that facilitates rapid assimilation by the pilot.

Attempts to reduce the difficulty of information assimilation have been made from two different viewpoints. With one method, individual items of information are combined in a computer and the combined signal is presented as a single indication; the number of indications is thereby reduced and, as an additional consideration, the indications can take the form of simple control commands (refs. 1 and 2). With the other method, the items of information are combined in the presentation itself, in a realistic or pictorial form that permits rapid interpretation in terms of the pilot's real-world experience (ref. 3).

In recent years the application of these two methods of combining information has led to the development of a wide variety of instrument displays. Since no detailed comparison of these displays has yet been made in terms of information content and form of presentation, it appeared appropriate at this time to assemble representative examples of the displays, to classify them in terms of basic display concepts, and to compare them on the basis of a common set of instrument display requirements. In the present report, eight displays have been selected for examination and comparison. As an introduction to the description of the displays, the subject of instrument display requirements is examined in some detail.

The displays considered in this paper include only those concerned with the landing-approach operation; that is, navigation, engine, and tactical displays are not included. Head-up displays are also excluded because they are generally intended for approaches to a breakout rather than landings under zero-zero conditions.

INSTRUMENT DISPLAY REQUIREMENTS

The term "instrument display requirements" is considered to denote two broad aspects of the display problem, namely, information content and information presentation. Although the two subjects will be discussed separately, the content and form of a presentation are in many cases interrelated. A given information content, for example, can usually be presented in a variety of forms. Conversely, a given form of presentation can be used to display different information contents.

Information Content

Although the information content for a VTOL landing display may vary with the aircraft configuration and with the type of powered-lift system, the requirement for attitude, guidance, and speed information is common to all types of VTOL aircraft. The basic information elements for each of these categories are listed in the following table:

Attitude	Guidance	Speed
Roll	Slope deviation	Airspeed
Pitch	Course deviation	Vertical speed
Heading	Range	Ground speed
	Height	

The items in this table of special interest to VTOL landing displays are range, course deviation, and ground speed, since these quantities are of primary importance in bringing an aircraft to a stop over a prescribed position. Height also requires special consideration since, for zero-zero operations, the information must be in terms of geometric height above the plane of the landing site. For any VTOL display, airspeed and vertical speed will probably be presented in the same general form as in CTOL and STOL displays. In the subsequent section on information presentation, the discussion is therefore confined to the presentation of attitude, guidance, and ground-speed information.

Information Presentation

The form of the information presentation of a complete display can be described in terms of:

- (1) the presentation of individual items of information
- (2) the presentation of combined information
- (3) the arrangement of the individual and combined presentations

The term "display concept" is used to describe major differences in the manner in which the attitude and guidance information is combined and arranged.

Information item presentation. - The primary factors relating to the presentation of individual items of information include:

- (1) the form and movement of the symbol
- (2) the "sensing" of the indication
- (3) the sensitivity and range of the scale

Secondary factors include symbol size and design; scale numerals and markings; and color, contrast, and brightness.

The form and movement of the symbol are generally dependent on the type of instrument. In electro-mechanical instruments, the symbol and its movement can take the form of rotating pointers, disks, and spheres and of linear-moving needles, tapes, and charts. With electronically generated displays on cathode ray tubes (CRT), both the form and the movement of the symbol can be much more complex. In electro-mechanical instruments,

the presentation of information items is generally in the form of abstract symbolism. With electronic displays, the symbol and its movement can be made to provide impressions of realism. Figure 1, for example, shows abstract and realistic presentations of two items of guidance information – a lateral control command and a slope deviation. In figure 1(a), both presentations indicate a left-turn command; in figure 1(b), both presentations show the aircraft to be above the slope. The two realistic-type indicators in figures 1(a) and 1(b) are described in references 4 and 5, respectively.

The "sensing" of an indication – that is, the direction of the symbol movement to signify a specified meaning – can be established from the viewpoint of either convention or real-world experience. As noted in reference 6, symbol movements can be selected from the viewpoint that numbered scales conventionally increase from left to right, from bottom to top, and clockwise. Thus, a thermometer-type presentation of height would be expected to move from bottom to top to indicate increasing height. For some information presentations, however, conventional scale sensing may prove inappropriate. In a thermometer-type presentation of range, for example, a more meaningful indication may be achieved if the scale increases from top to bottom.

The sensing of indications from the standpoint of real-world experience has been expressed in terms of (1) the relative motions the pilot sees from the cockpit ("inside-out" concept), and (2) the relative motions that would be seen from an imaginary point outside the aircraft ("outside-in" concept). The presentation of attitude and guidance information with the "inside-out" concept requires that the signifying symbol move, with respect to a fixed aircraft symbol, in a direction opposite to the aircraft movement. With an "inside-out" heading indication, for example, the compass card on a conventional horizontal-situation indicator rotates to the left when the aircraft rotates to the right (fig. 2(a)); with an "inside-out" course-deviation indication, the course bar moves left as the aircraft moves to the right of the course (fig. 2(b)).

An interesting aspect of the "inside-out" and "outside-in" concepts is the fact that with linear-moving indications the appearance of the presentations is essentially the same, whereas with rotational indications the appearance of the presentations can be quite different. Illustrations of linear-moving and rotational indications by the two concepts are given in figure 3. In figure 3(a) pitch attitude is indicated by (1) an artificial horizon that moves vertically with respect to a fixed aircraft symbol ("inside-out" concept), and (2) an aircraft symbol that moves vertically with respect to a fixed artificial horizon ("outside-in" concept). In figure 3(b) roll attitude is indicated by (1) an artificial horizon that rotates with respect to a fixed aircraft symbol ("inside-out" concept), and (2) an aircraft symbol that rotates with respect to a fixed artificial horizon ("outside-in" concept). The application of the two sensing concepts in two conventional attitude indicators is shown in figure 4. In figure 4(a) both roll and pitch are presented with the

"inside-out" concept; in figure 4(b) roll is presented with the "inside-out" concept and pitch with the "outside-in" concept. In the illustration, both instruments indicate a roll to the right and a pitch-down attitude.

The sensitivity and range of the scale required of a given measurement can vary with the phase of the landing operation. For the deceleration-to-hover phase, the required sensitivity for position information is obviously much greater than that required during the initial phase of the approach; similarly, the scale ranges for the deceleration phase can also be much smaller than for the initial phase. In the scaling of position information for the deceleration phase, an important consideration is the fact that, if the sensitivity of the displacement information is sufficient, usable rate information may be derived from the motion of the displacement indication; this consideration is of particular interest as a means of presenting ground-speed information.

The sensitivity and range that can be achieved in practice depend on the size and type of instrument. With the conventional sphere-type attitude indicator, for example, the sensitivity of the pitch-attitude indication is about one-eighth the apparent linear displacement of the real horizon; with roller-screen-type attitude indicators, the pitch sensitivity can be increased considerably; and with large CRT displays, the sensitivity can approach 1:1 correspondence with the movement of the real horizon. For the presentation of position information, the sensitivities of conventional guidance indicators are generally low with respect to the sensitivities required for VTOL landings. With moving-chart indicators (particularly optical-projection indicators having large chart-storage capacities), much larger sensitivities can be achieved.

Combined information presentations. - As noted in the Introduction, items of information can be computer-combined for presentation by a single symbol or the information can be combined in the presentation itself in a realistic or pictorial form.

The nature of the information combined for a single symbol will, of course, determine the meaning of the indication. The combination of a displacement and its rate produces a so-called "quickened" indication (ref. 7); the addition of attitude information to this combination produces a "control command" (ref. 8); with the further addition of control-position information, the combined signal becomes a "control demand" (ref. 9). Both control commands and control demands have also been called "flight-director commands."

The combination of information in realistic form can vary from a simple combination of two items of information to a complex combination of several items; for any given combination, both the form and degree of the realism can also vary. The most realistic combination of all the attitude and guidance information is, of course, a real-world presentation. With present display techniques, such a perspective presentation would require the use of a CRT-type indicator. With the simpler mechanical and optical instruments,

however, portions of the attitude and guidance information can still be presented in realistic form. Roll and pitch, for example, are combined with a degree of realism on the conventional two-axis attitude indicator (fig. 4(a)); and roll, pitch, and heading, on the conventional three-axis attitude indicator (fig. 5(a)). These combinations of related information suggest the further combination of course deviation since, in the real world, heading and course deviation are intimately related; a real-world combination of these four items would, of course, be difficult to achieve with simple instrument displays. As shown in figure 5, however, other combinations of related information such as slope deviation, range, and height (fig. 5(b)) and course deviation, range, and heading (fig. 5(c)) can be presented with relatively simple display techniques.

Arrangement of information.- The problem of arranging individual and combined information presentations is one of reducing the pilot's scan pattern and creating a logical scan sequence. In practice, the problem is generally reduced to grouping auxiliary instruments around the major attitude and guidance indicators. The cockpit display of reference 10 is an example of an information arrangement designed to minimize the scan problem (see fig. 6). In the subsequent discussion of display concepts, the arrangement of information is mentioned only occasionally, since the primary emphasis is on the combination of information.

DISPLAY CONCEPTS

An indication of the variety of ways in which attitude and guidance information has been combined and arranged is shown by the group of displays in figure 7. Although many other displays have been devised, the ones shown in the figure generally represent the scope of the basic display concepts that have been employed. As indicated in the figure, these concepts are grouped in four major categories:

- (1) Separated vertical-horizontal displays
- (2) Combined vertical-horizontal displays
- (3) Pseudo-perspective displays
- (4) Perspective displays

The first two categories are subdivided into displays in which the symbolism is, for the most part, either abstract or realistic. The last two categories differ in the apparent plane in which the symbols are displayed; with the pseudo-perspective displays the symbols are generated in a screen-coordinate system, whereas with the perspective displays they are generated in a ground-coordinate system. The instruments for the displays in the first category are either electro-mechanical or electro-optical types; the display indicators in the last three categories are all CRT types.

In the following sections, the individual displays are described in detail. Two enlarged photographs are presented for each display – one with the items of information labeled and the other without labels. Wherever possible, the items on attitude and guidance are listed separately. Items of information that are combined in the presentation are grouped and designated with a bracket. In addition to the items on attitude and guidance, ground speed is also labeled. For those displays in which ground speed is derived from motions of the range and course-deviation indications, it is grouped with these items.

Separated Vertical-Horizontal Displays

Abstract symbolism. - Display A-1 (fig. 8) is generally representative of conventional attitude-guidance displays in the sense that the information is presented, for the most part, as individual items and in abstract form. Roll, pitch, and slope deviation are presented on the vertical-situation indicator, and heading and course deviation are presented on the horizontal-situation indicator. Range, height, and ground speed are presented individually on vertical-scale indicators. Range markers for 3000, 4000, and 5000 feet (914, 1219, and 1524 meters) are presented by three lights below the vertical-situation indicator.

Course guidance is also presented as a flight-director command on the vertical cross pointer of the vertical-situation indicator. The horizontal cross pointer is normally used for the presentation of a flight-director command for slope guidance, but for the tests of this display in reference 11, it was used to indicate deviations from a reference pitch attitude.

The arrangement of the vertical-scale indicators around the vertical- and horizontal-situation indicators was made from the viewpoint of grouping related information. The airspeed indicator, for example, was placed alongside the reference pitch indicator, and the vertical-speed indicator was placed below the airspeed indicator. The height indicator was located beside the slope-deviation indicator, with the range indicator placed below the height indicator so that the two tapes would move toward each other as the approach progressed. The ground-speed indicator was located alongside the height and range indicators because of the importance of ground speed in the final phase of the approach.

Display A-1 is the first display tested in the Langley Research Center (LRC) VTOL display program. The display was evaluated in a helicopter having no form of artificial stabilization. The tests were conducted in 30-knot approaches on a 6° glide slope to a breakout at 50 feet (15.24 meters); all approaches were made under simulated IFR (Instrument Flight Rules) conditions. (See ref. 11.)

Realistic symbolism.- Display A-2 (fig. 9) is one in which the slope and course guidance information is presented in moving, realistic formats. Slope deviation and range are presented in combined form on a mechanical, height-range indicator to the left of the attitude indicator. The aircraft symbol moves vertically from inputs of height, and the screen, on which the glide slope and slope boundaries are inscribed, moves laterally from inputs of range.

Course deviation, range, and heading are presented in combined form on the moving-map indicator below the attitude indicator. The map indicator is an optical type that projects a ground chart and an aircraft symbol. The chart moves laterally and vertically from inputs of course deviation and range, and the aircraft symbol rotates from heading inputs to indicate relative heading - that is, orientation with respect to the course line. Course boundaries are inscribed on each side of the course line to indicate allowable course deviations. The motion of the map provides qualitative impressions of ground speed, as does also the lateral motion of the screen on the height-range indicator.

The attitude indicator of this display was designed to present roll and pitch on a roller-screen artificial horizon having a pitch sensitivity about three times that of the conventional attitude indicators of figures 4 and 5(a). The vertical tape on the left of the artificial horizon presents a sensitive indication of height.

The individual and combined information presentations of this display were arranged to provide a circular scan sequence in terms of control tasks, with attitude control at top center, speed control at top right, course guidance at the bottom, and slope guidance at top left.

Display A-2 was developed for evaluation in the LRC VTOL display program. The moving-map indicator of this display was evaluated in a display that was essentially the same as display A-1 except for the replacement of the horizontal-situation indicator with the map indicator. The tests of this display (ref. 12) were conducted in the same helicopter as display A-1 and with the same task, namely, 30-knot, 6° approaches to a 50-foot (15.24-meter) breakout.

Combined Vertical-Horizontal Displays

Abstract symbolism.- Display B-1 (fig. 10) is an electronically generated display in which vertical- and horizontal-situation information has been superimposed. The attitude presentation is similar to that of display A-1 in indicating roll and pitch by an artificial horizon line and heading by a rotating compass ring. The aircraft reference symbol for this display consists of the small circle at the center, the vertical heading reference line, and the horizontal roll-pitch reference line (the right-angled symbols on each side of the circle).

The symbol configuration of this display can be varied for different flight modes — that is, for navigation, landing approach, and hover. Figure 10 shows the landing-approach configuration with the addition of a ground-speed vector, which is the only additional symbol used for the hover configuration.

Slope and course guidance information is presented as flight-director commands on the cross pointers. Range information is presented in the form of a contracting circle, and height in the form of a digital counter. Ground-position information (range, course deviation, and heading) is presented by the circle-angle symbol that indicates the position and orientation of the approach zone and landing area. In the hover mode, ground speed is indicated by a velocity vector that extends outward from the circle of the aircraft symbol.

Tests of this display have been conducted in a VTOL simulator (ref. 13). In these tests, 10 pilots executed 100 approaches to VTOL landings within a 66-foot-diameter (20-meter) circle.

Realistic symbolism.— Display B-2 (fig. 11) is an electronically generated display in which a sense of realism is created by combining the vertical- and horizontal-situation information in a simulated forward-looking view. Heading, for example, is combined with roll and pitch as a numbered scale along the artificial horizon line. In addition, a checker-board pattern is presented at the bottom of the screen to represent a ground grid that moves laterally and vertically to indicate speed over the ground.

Like display B-1, the symbol configuration of display B-2 can be changed for different flight modes; the configuration in figure 11 is the hover configuration with the addition of a cross, which is the only additional symbol used for the landing-approach configuration. The cross is used to present flight-director commands for slope and course. Range is presented in two forms: (1) as a thermometer-type indication along the top of the screen, and (2) as a vertical line (with short cross bar) that increases in length to indicate decreasing range to the landing site. The vertical-line—cross-bar symbol also moves laterally to indicate course deviation. This range—course-deviation indicator provides a degree of realism in that the vertical line can be considered as a pole located beyond the landing pad. When the "pole" reaches the horizontal reference lines at the top and bottom of the screen, it indicates that the aircraft is over the center of the landing pad. Height information is presented in the form of a counter at the top right of the screen; the index to the left of the counter indicates variations from a command altitude.

This display is an experimental model currently being developed for VTOL display studies at the Institute for Flight Research, German Research Institute for Air and Space Travel.

Psuedo-Perspective Displays

Displays C-1 and C-2 (figs. 12 and 13) are electronically generated displays in which all the symbols are generated in screen coordinates. The displays are called psuedo-perspective because the pathways are not displayed in ground coordinates as in the perspective displays. Although these particular displays cannot be considered landing displays (since neither presents range information and display C-2 contains no slope and course guidance information), they are included in the present survey to illustrate the kind of symbol forms that have been developed for screen-coordinate displays.

With display C-1, the tip of the pathway moves laterally and vertically to indicate flight-director commands for slope and course guidance. This movement of the path tip is similar to that shown in figure 1(a). The pathway of display C-1, however, has the additional feature that its width can be made to expand and contract to indicate changes in height from a command height or from a glide slope. The segments to the right of the path are used to indicate deviations from a command airspeed, but they could also be used to indicate ground speed. For the command-airspeed indication, the segments move downward if the speed is too high, move upward if the speed is too low, and are stationary if the speed is correct. For a ground-speed indication, the segments would move downward to indicate forward speed over the ground. The attitude presentation includes roll and pitch but no heading information.

With display C-2, the pathway is used to indicate speed rather than guidance. As with display C-1, the motion of the path segments could be used to indicate either ground speed or deviations from a command airspeed. Heading is presented as a numbered scale along the artificial horizon (as in display B-2), and height is presented as a numbered scale that moves vertically on the left side of the screen.

Displays C-1 and C-2 have been proposed as vertical-situation displays for the Integrated Helicopter Avionics System (IHAS) described in references 14 and 15. Horizontal-situation information will be presented on some form of map display.

Perspective Displays

Contact analog.- The contact analog of display D-1 (fig. 14) is an electronically generated display that presents a stylized representation of the real world in perspective format. The presentation of this contact analog is created from four symbols: horizon line, ground grid, landing pad, and pathway. The grid, pad, and pathway are all generated in a ground-coordinate system.

The pathway and landing pad change size, shape, orientation, and position with inputs of aircraft attitude and position. The ground grid changes size, shape, and

orientation with aircraft attitude and height, but moves laterally and vertically with aircraft-position rates rather than with aircraft position. Thus, with aircraft motion, the ground grid appears to translate underneath the pathway and landing pad.

The ground-coordinate symbols of this contact analog are generated to correspond to specified real-world dimensions. The scene in figure 14 shows the symbol sizes for an aircraft height of 150 feet (45.72 meters) and a range of 1500 feet (457.2 meters) from the pad.

Since the pathway is inclined to the ground grid, it inverts to the top of the screen whenever the aircraft is below the pathway. To avoid pathway inversion, therefore, it is necessary to set the actual glide slope an appreciable distance (about 50 feet or 15.24 meters) above the pathway. In the scene in figure 14, the pathway is inclined at an angle of 6° and set at a distance of 50 feet (15.24 meters) below the glide slope.

The angular view of this contact analog is 24° horizontal and 18° vertical. Because of the limited vertical view, the near edge of the pathway (i.e., the section at the bottom of the screen) is a considerable distance ahead of the aircraft when the aircraft is 50 feet (15.24 meters) above the pathway. Thus, with the aircraft in a 3° nose-down attitude (a typical value for 30-knot, 6° approaches with the helicopter used in the LRC VTOL display program), the far end of the pathway can be lost from view when the aircraft is at a height of about 100 feet (30.48 meters).

In display D-1, two thermometer-type height indicators (with different ranges) were added to supplement the qualitative impression of height provided by the ground grid. This display has recently been evaluated, as a part of the LRC VTOL display program, in 30-knot, 6° approaches with the same helicopter used for the tests of display A-1. The approaches were carried to breakout heights that were determined by the height at which the pathway was lost from view, generally about 100 feet (30.48 meters).

In previous tests of a contact analog similar to that of figure 14, 65-knot approaches were flown on an 8° slope with a helicopter (ref. 16). These approaches were terminated, by the safety pilot assuming control, at various heights above the ground.

Display simulator. - The display simulator of display D-2 (fig. 15) consists of a ground-based model of a landing site that would be televised to the aircraft. The scene in figure 15 is of a preliminary-study model that was photographed with a closed-circuit television system to illustrate the quality of the presentation.

The essential elements that comprise the model scene are the horizon line, the runway grid and landing pad, the two rows of vertical tee bars, and the two erect rectangles beyond the landing pad. The angular view of the scene is 28° horizontal and 21° vertical.

The most significant aspects of the model, from an information-presentation standpoint, include (1) the horizon and course-line arrangement that provides a combined presentation of roll, pitch, heading, and course deviation in a real-world format, and (2) the runway grid to provide ground-speed and range information as normally derived in the real world. The runway is scaled in terms of real-world dimensions of 100 feet (30.48 meters) in width and 1000 feet (304.8 meters) in length.

Two other features of interest include the array of tee bars for slope guidance and the two erect rectangles for zero-range indication. The tops of the tee bars are aligned along a 6° slope, and the bars are placed on each side of the runway to allow the television camera to move down the center of the glide slope. The two rectangles beyond the pad are so sized and positioned that their widths appear equal when the aircraft is over the center of the landing pad – that is, at zero range.

Display D-2 is being considered for testing as a part of the LRC VTOL display program.

DISCUSSION

Of the eight displays described in the previous section, four present guidance information in the form of flight-director commands. With one of the four (display B-1), VTOL landings were performed in an aircraft simulator. In unpublished tests of other displays, similar to B-1 in presenting most of the information in abstract form and guidance as flight-director commands, VTOL landings also have been performed in aircraft simulators. However, as far as is known, no VTOL landings have yet been achieved in actual aircraft with abstract-symbol, flight-director displays.

In flight trials of a display with only one flight-director command (display A-1), the pilots were not only unable to perform landings; they were generally unable to bring the helicopter to a hover. In fact, they also experienced difficulties in maintaining uniform control during constant-speed approaches (at 30 knots). These difficulties were due both to the low-speed control characteristics of the helicopter and to deficiencies in the display. The difficulties in using the display were attributed to (1) the display of the information individually and in abstract form, (2) the constantly changing indications resulting from the low-speed flight condition, and (3) the fact that the flight-director command for course guidance absorbed so much of the pilot's attention that insufficient time was left for the control of the other tasks.

As noted previously, the moving-map indicator of display A-2 was evaluated with the display reported in reference 12. It was found that a high degree of realism was created by the map presentation of course deviation in a range-moving format. This map presentation, in combination with the realistic presentation of heading, provided a

display in which the interpretation of the course guidance information was almost immediate. As a result, more time was left for the control of the other tasks than with the flight-director command of display A-1. In a comparison of these displays in reference 17, it was concluded that, for low-speed operations, a more uniform control of the overall approach task may be achieved with a pictorial display of guidance information than with a computer-generated flight-director command.

The concept of displaying course-deviation information in a range-moving format is extended, in display A-2, to the presentation of slope deviation. With the contact analog of display D-1, the concept is further extended by the combination of both slope and course deviation in a single range-moving format – that is, the inclined pathway.

Although this pathway presentation would appear to provide a high degree of realism, difficulties were experienced in using it because of the limited angular view of the display. With the limited horizontal view, the pathway can be lost from view with relatively small changes in heading and course deviation. In addition, heading changes cause the pathway to move laterally in such a way as to produce false impressions of course deviation. With the limited vertical view, the section of the pathway at the bottom of the screen can be a considerable distance ahead of the aircraft, as noted previously; as a result, slope deviations can be difficult to detect and changes in pitch attitude can be misinterpreted as slope deviations (since the path width changes with both pitch and slope deviation). In spite of these difficulties, however, the LRC flight tests of the display showed that the realistic presentation of slope and course guidance in combination with attitude information represented an improvement over the separated vertical- and horizontal-situation presentation in display A-1 and the moving-map display of reference 12.

In the final phase of the approach, where the guidance information of the contact analog is reduced to that provided by the pathway and ground grid, additional difficulties were encountered because of the manner in which the ground grid was generated. The translation of the grid from rate inputs, for example, produced relative motions of the grid with respect to the pad and a resulting loss of realism. In addition, the scaling of the grid was such that only a few large squares were visible when the aircraft was close to the ground and near the pad. As a result, the grid and pad combination did not provide ground-position information in a form that would permit controlled decelerations to hover.

With another form of real-world display, however, helicopters have been brought to a hover and landed under simulated IFR conditions. This form of information display was generated by a closed-circuit television system with the camera mounted on the helicopter (refs. 18 and 19). As far as is known, this is the only form of display with which VTOL landings have been accomplished with actual aircraft.

The LRC display of reference 19 is shown in figure 16 with an actual photograph of the test airfield in the place of the monitor screen. This photograph is intended to show the detail of the runway grid ahead of the landing pad and the area covered by the angular view of the camera lens (23° horizontal and 19° vertical). The scene was photographed from a height of about 100 feet (30.48 meters) and a range of about 1000 feet (304.8 meters) from the landing pad.

Although the televised scene in the flight tests was that of the real world, it should be realized that this displayed scene was deficient in several respects in comparison with the view of the real world as normally seen by the pilot. Aside from the obvious lack of depth perception, low resolution, and lack of color, the displayed scene was deficient because of the limited view angle and because the sizes of images on the screen were smaller than they would be if seen under normal viewing conditions. As discussed in reference 19, this latter effect was due to the pilot's visual angle being smaller than the camera lens angle.

With the limited view angle, the pilots encountered some of the same difficulties that were experienced when the contact analog of display D-1 was used. In performing touchdowns, however, the pilots experienced additional difficulties, because of the limited vertical view, in determining the prescribed longitudinal position for touchdown – that is, zero range.

Because the sizes of the images on the television screen were different from their real-world sizes, the position information (particularly range and height) that was derived from the displayed scene was incorrect. This lack of correct position information did not appear too troublesome during the initial part of the approach, for pilots were able to bring the helicopter to a hover at a height of about 25 feet (7.62 meters) without great difficulty. For the final phase, however, they were able to continue to touchdown only by repeated comparison of the displayed scene with the sensitive height indicator.

In the LRC tests the same monitor was used for both the television and contact-analog displays. The two displays were the same, therefore, in regard to screen size and picture resolution, and were essentially the same in regard to the angular view of the displayed scene. In addition, the two displays were alike as regards the deficiencies in the displayed position information; just as the position information of the television display was incorrect, the position information on the contact analog had no real-world significance to the pilot (even though the symbols were generated in terms of real-world dimensions).

The two displays were also alike in the sense that both displayed a ground grid in the final phase of the approach. The grids of the two displays were different, however, in that (1) the runway grid on the television display provided a definite course center line and a more detailed grid pattern, and (2) the ground grid of the contact analog translated

with aircraft-position rate rather than with aircraft position. These differences in the form and motion of the two grids are believed to have accounted, for the most part, for the fact that the pilots were able to perform controlled decelerations to hover with the television display but were unable to do so with the contact analog.

The experience with the closed-circuit television system in the LRC tests suggested that a perspective display incorporating a detailed grid pattern, fixed in ground coordinates, might provide guidance information in a form that would permit controlled decelerations and touchdowns. The display simulator of display D-2 represents an attempt to create such a display. Although the creation of the model scene is comparatively simple, the transmission system required to display the scene in the aircraft is rather complex. This system would require that the television camera be mounted on a three-axis gimbal supported on a three-axis translation mechanism above the model ground scene. The camera would translate with aircraft-position inputs, as measured by a ground-based radar, and would rotate with aircraft attitudes, as sensed on the aircraft and telemetered to the display simulator. Thus, the control of attitude and guidance with this display would be expected to be less precise than with the closed-circuit television system because of errors in the attitude and position inputs and in the camera rotational and translation mechanism. On the other hand, slope guidance and longitudinal touchdown positioning might be more precise with the display simulator because of the inclusion of the glide slope and touchdown-position symbols in the model scene.

It is possible, of course, that a ground scene such as that proposed for the display simulator could be produced electronically, as in the contact analog; thus the advantage of an onboard display system would be retained. It is also possible that other forms of display, less complex than a perspective real-world type, may prove satisfactory for the deceleration and touchdown phase of VTOL landings. The possibility that the display requirements may be eased by improvements in aircraft controllability through the use of artificial stabilization must also be considered. At the present time, however, there is insufficient evidence from flight tests to assess any of these possibilities.

CONCLUDING REMARKS

A variety of concepts for the display of attitude and guidance information for the landing of VTOL aircraft have been described. The basic differences in the concepts related to the form of symbolism (abstract or realistic) and to the manner in which items of information were combined. With some displays, guidance information was combined in computers as flight-director commands, whereas with other displays the information was combined in the presentation itself in realistic or pictorial form.

Flight tests of two of the displays in a helicopter indicated that, in simulated IFR approaches to a 50-foot (15.24-meter) breakout, better performance of the approach task was achieved with the guidance information in realistic form than in the form of a flight-director command. With the most realistic presentation of attitude and guidance information that has been achieved with present display techniques (the real-world display of a closed-circuit television system), VTOL landings of helicopters have been accomplished under simulated zero-zero conditions. On the basis of this flight experience, a televised presentation of a simulated real-world landing site was suggested as a possible form of display for achieving VTOL landings under zero-zero conditions.

Langley Research Center,

National Aeronautics and Space Administration,

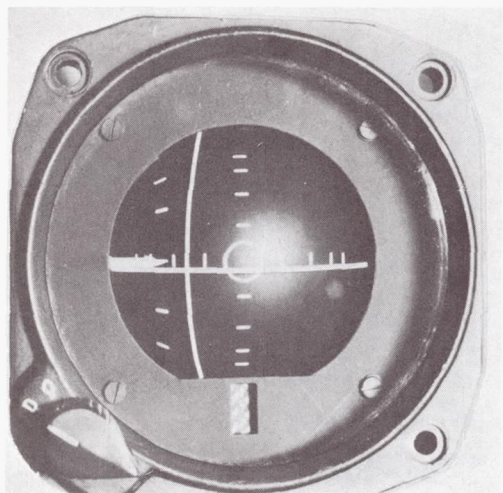
Langley Station, Hampton, Va., July 26, 1968,

721-04-00-16-23.

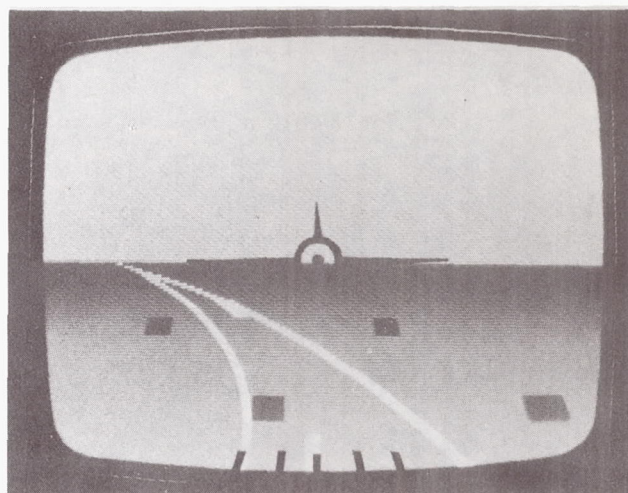
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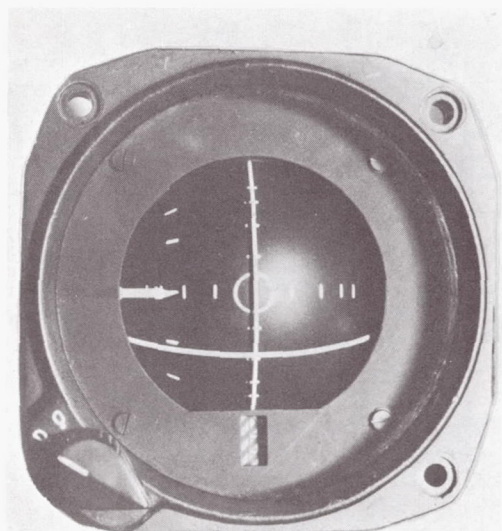


Abstract

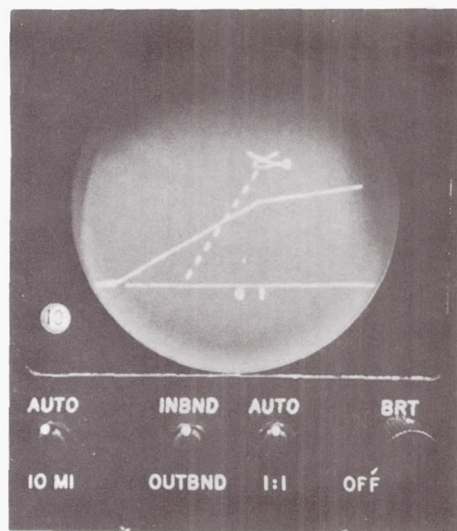


Realistic

(a) Lateral control command.



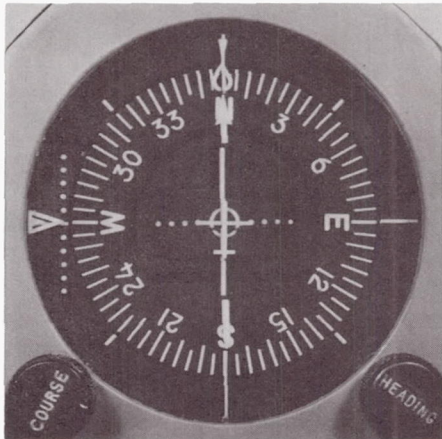
Abstract



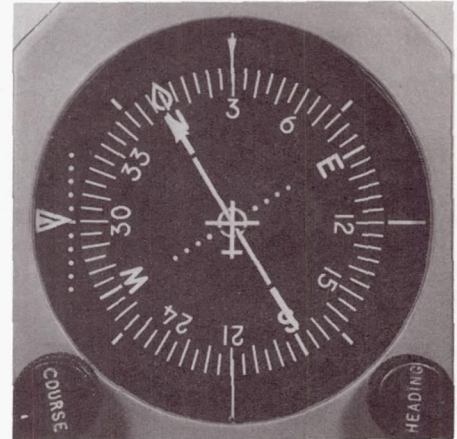
Realistic

(b) Slope deviation.

Figure 1.- Abstract and realistic presentation of guidance information.

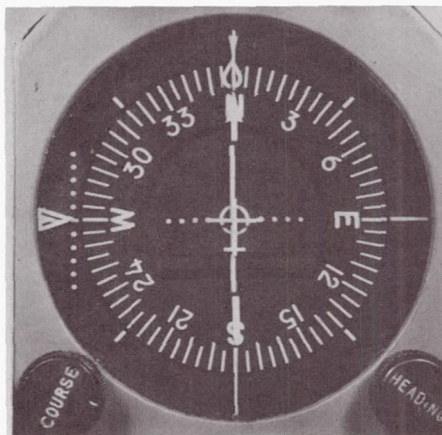


On command heading

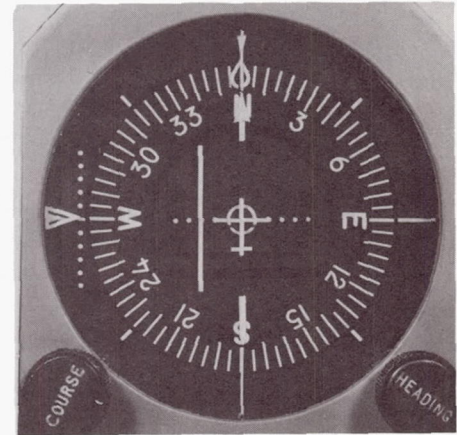


Rotation to right
of command heading

(a) Heading indications.



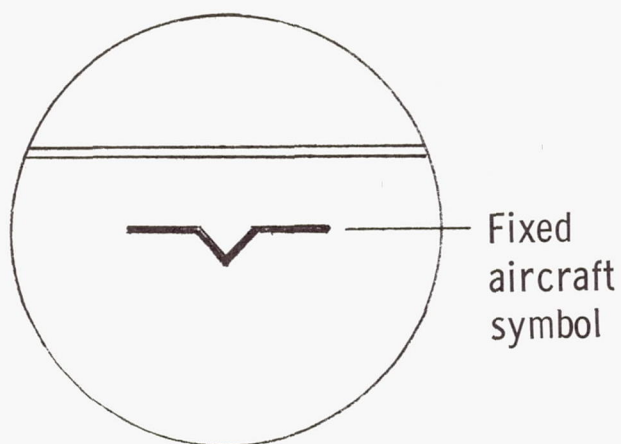
On command course



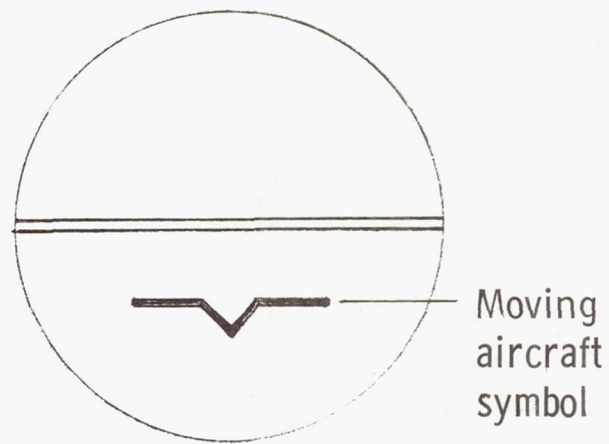
Displacement to right
of command course

(b) Course-deviation indications.

Figure 2.- Presentation of heading and course deviation by "inside-out" concept; illustration of principle that signifying symbol moves in opposite direction to aircraft movement.

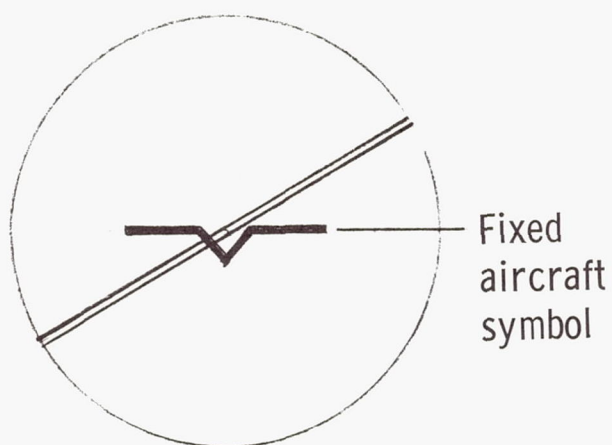


"Inside-out" concept

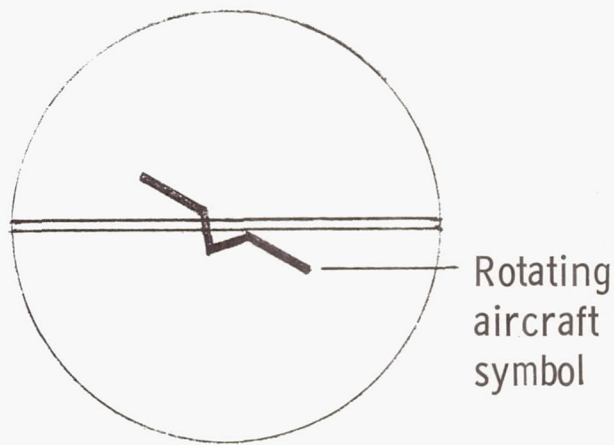


"Outside-in" concept

(a) Linear-moving indication (for pitch attitude).



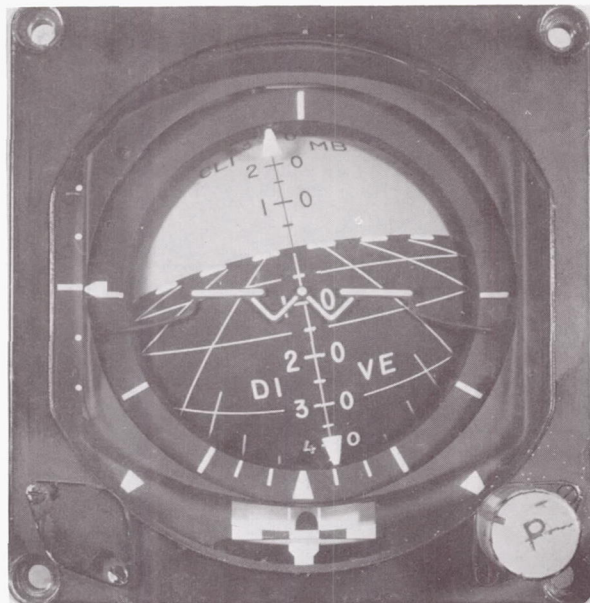
"Inside-out" concept



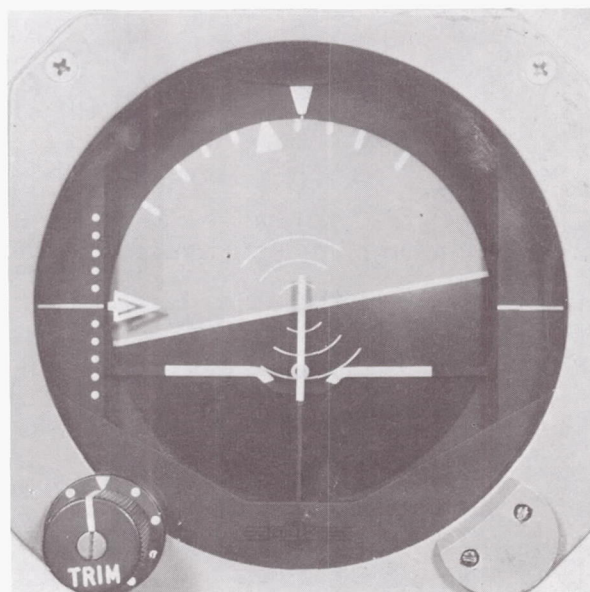
"Outside-in" concept

(b) Rotational indication (for roll attitude).

Figure 3.- Presentations of linear-moving and rotational indications by "inside-out" and "outside-in" concepts; illustration of similarity in appearance of linear-moving presentations and difference in appearance of rotational presentations.

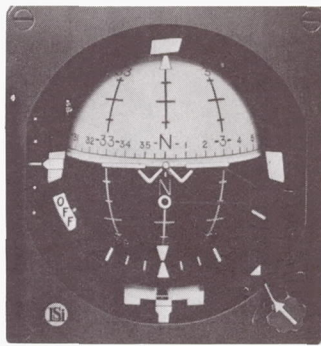


(a) Roll and pitch indicated by "inside-out" concept.

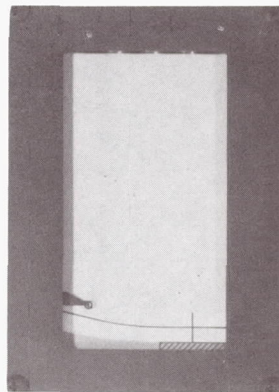


(b) Roll indicated by "inside-out" concept; pitch indicated by "outside-in" concept.

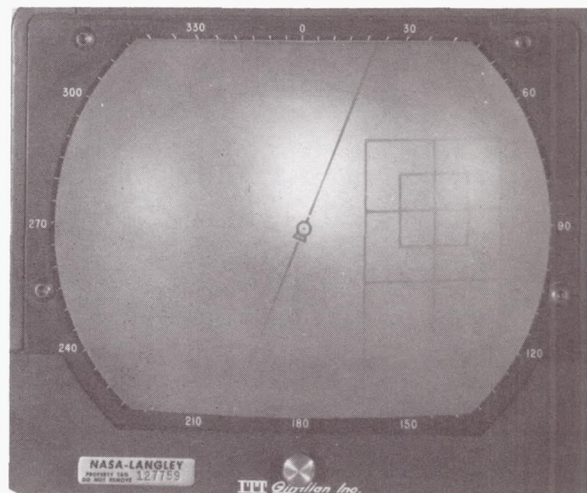
Figure 4.- Application of "inside-out" and "outside-in" concepts in two conventional attitude indicators.



(a) Combination of roll, pitch, and heading.



(b) Combination of slope deviation, range, and height.



(c) Combination of course deviation, range, and heading.

Figure 5.- Examples of presentations in which related information is combined in realistic form.

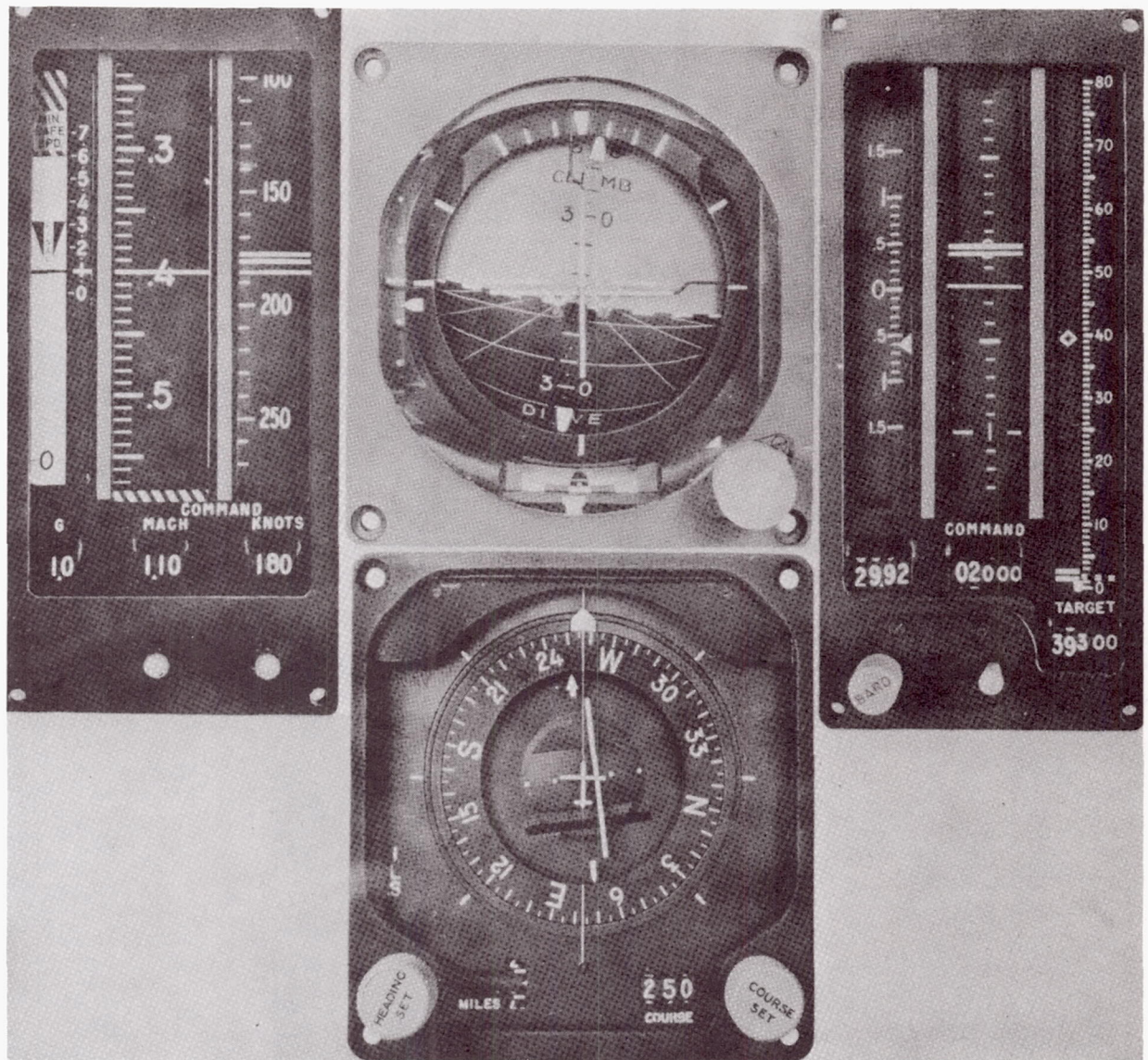
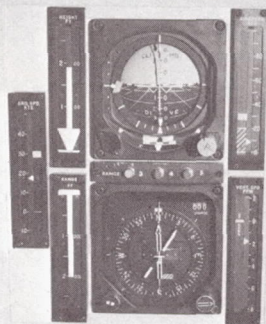
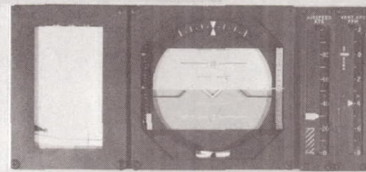


Figure 6.- Cockpit display illustrating arrangement of information to minimize scanning problem.

SEPARATED VERTICAL - HORIZONTAL DISPLAYS

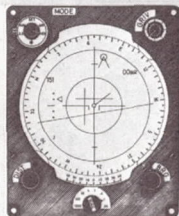


A-1
(ABSTRACT SYMBOLISM)

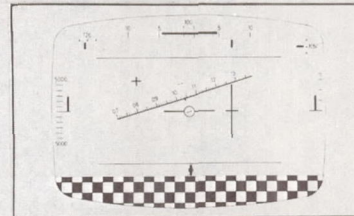


A-2
(REALISTIC SYMBOLISM)

COMBINED VERTICAL - HORIZONTAL DISPLAYS

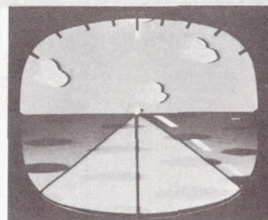


B-1
(ABSTRACT SYMBOLISM)

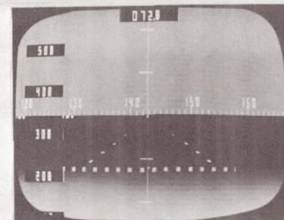


B-2
(REALISTIC SYMBOLISM)

PSUEDO - PERSPECTIVE DISPLAYS

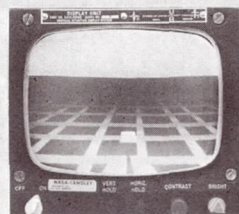


C-1

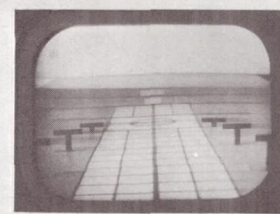


C-2

PERSPECTIVE DISPLAYS



D-1
(CONTACT ANALOG)

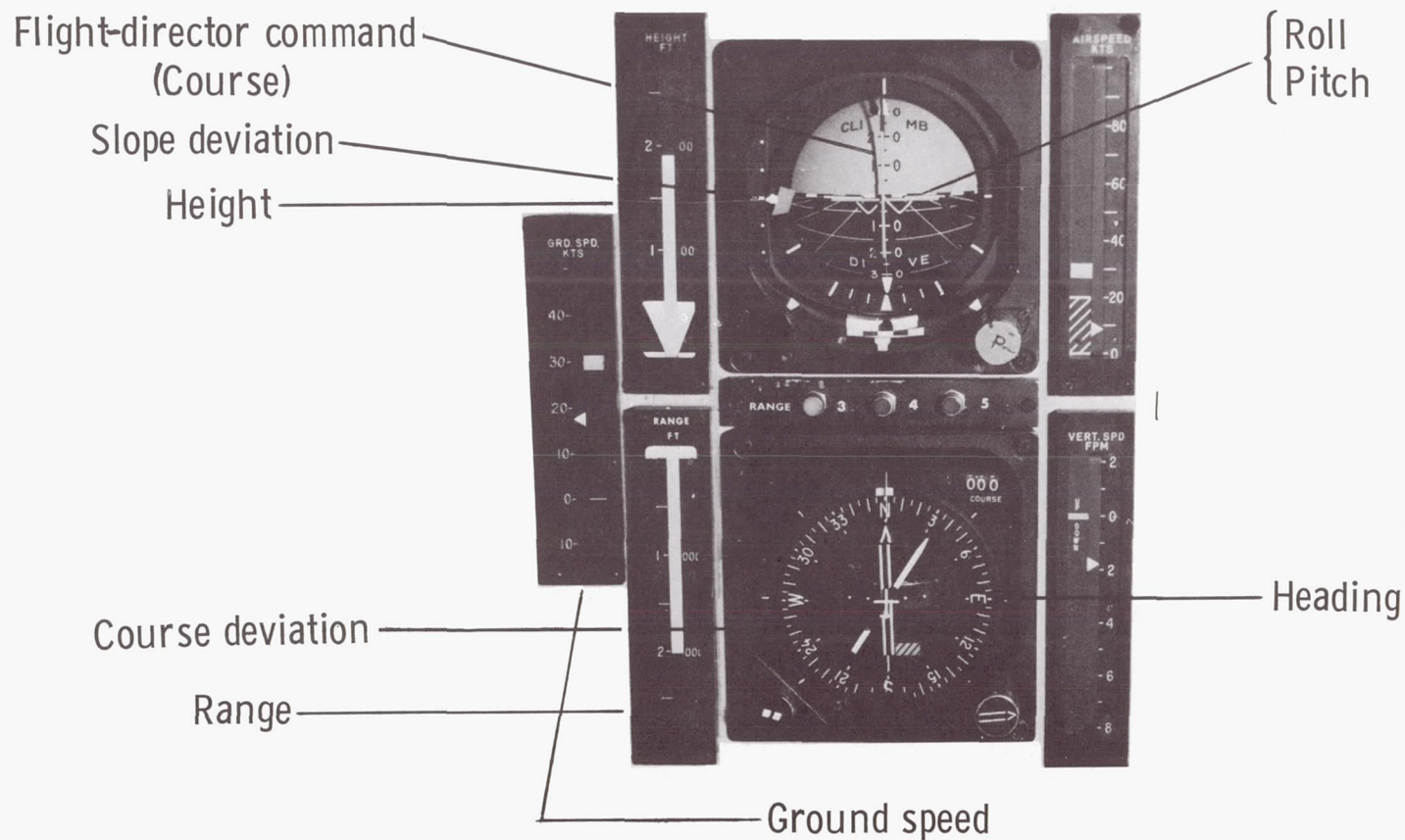


D-2
(DISPLAY SIMULATOR)

Figure 7.- Display concepts for the presentation of attitude and guidance information.

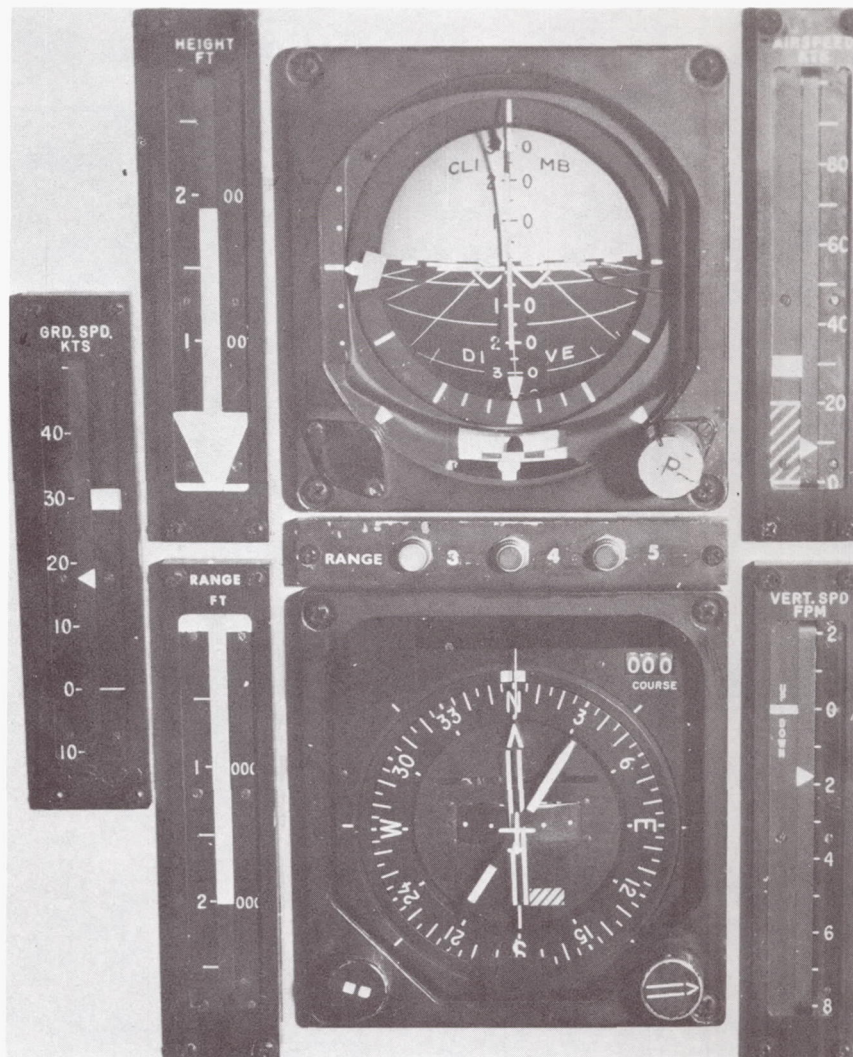
GUIDANCE

ATTITUDE



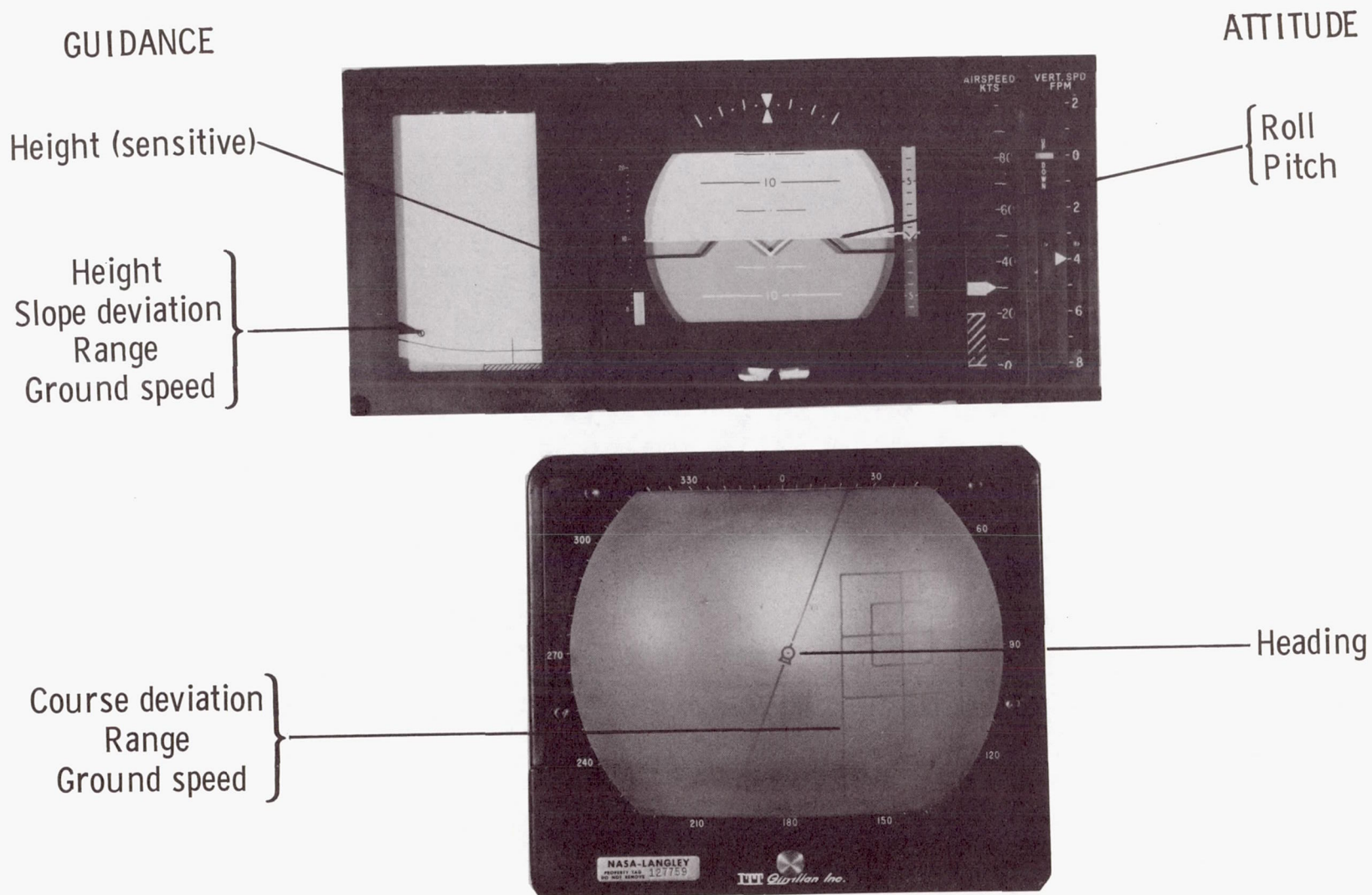
(a) Labeled.

Figure 8.- Display A-1.



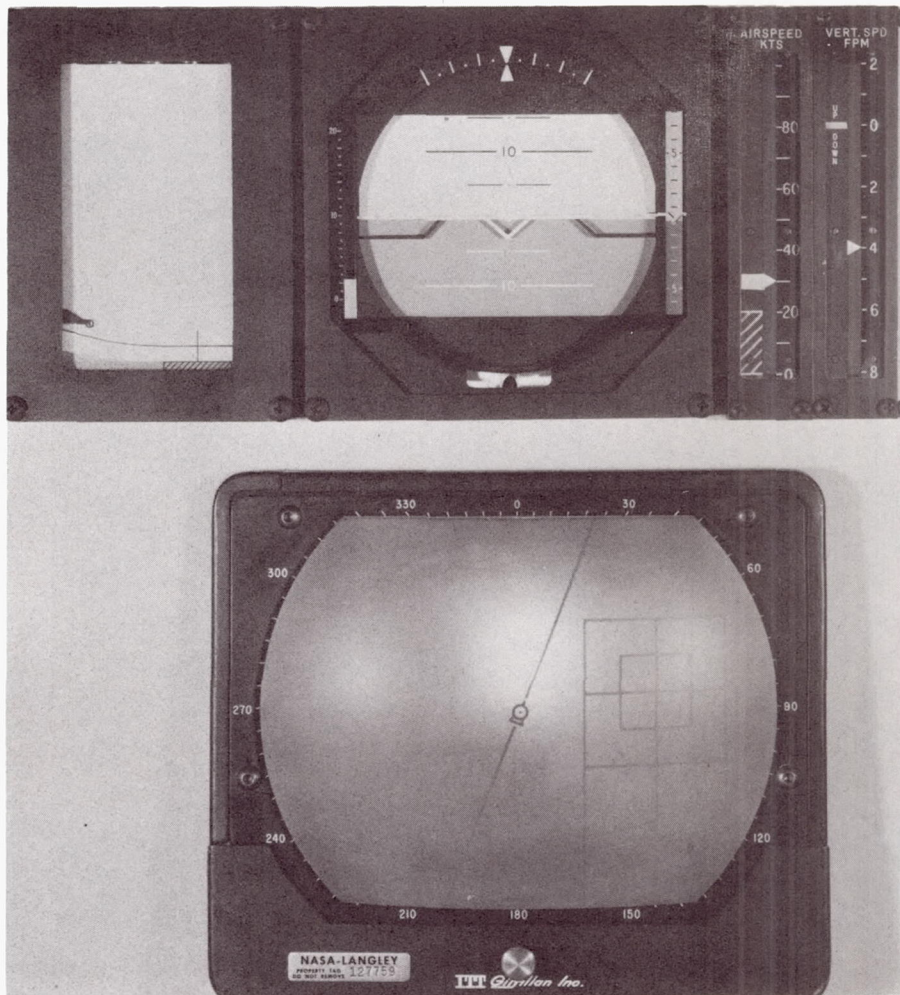
(b) Unlabeled.

Figure 8.- Concluded.



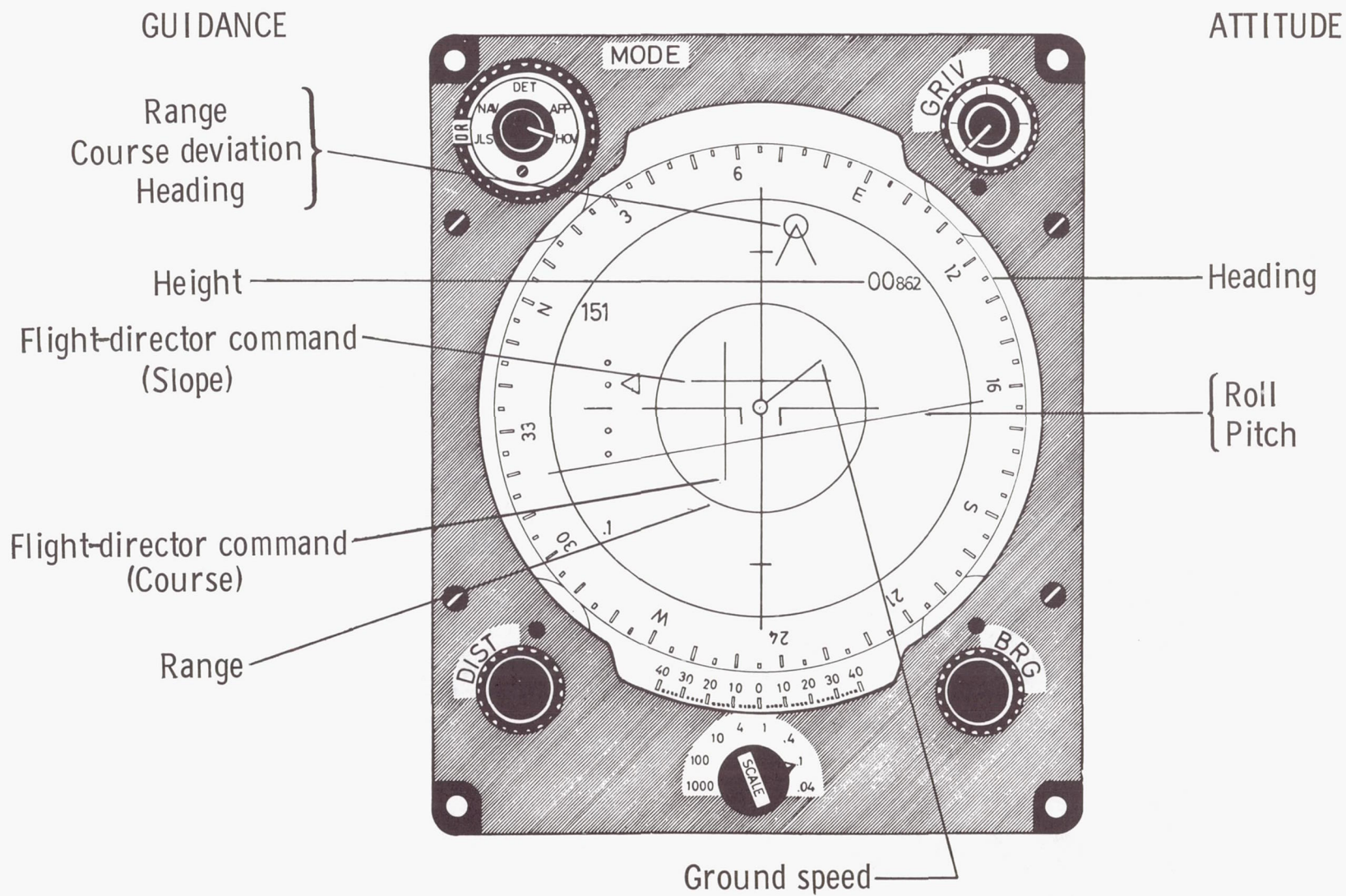
(a) Labeled.

Figure 9.- Display A-2.



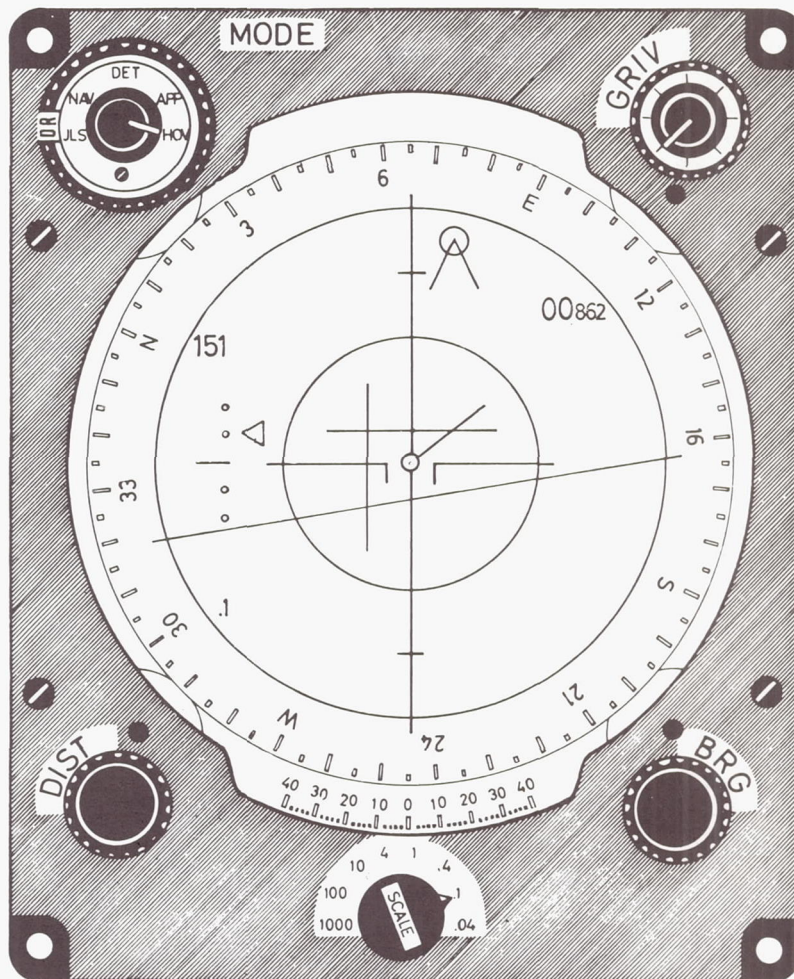
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Figure 9.- Concluded.



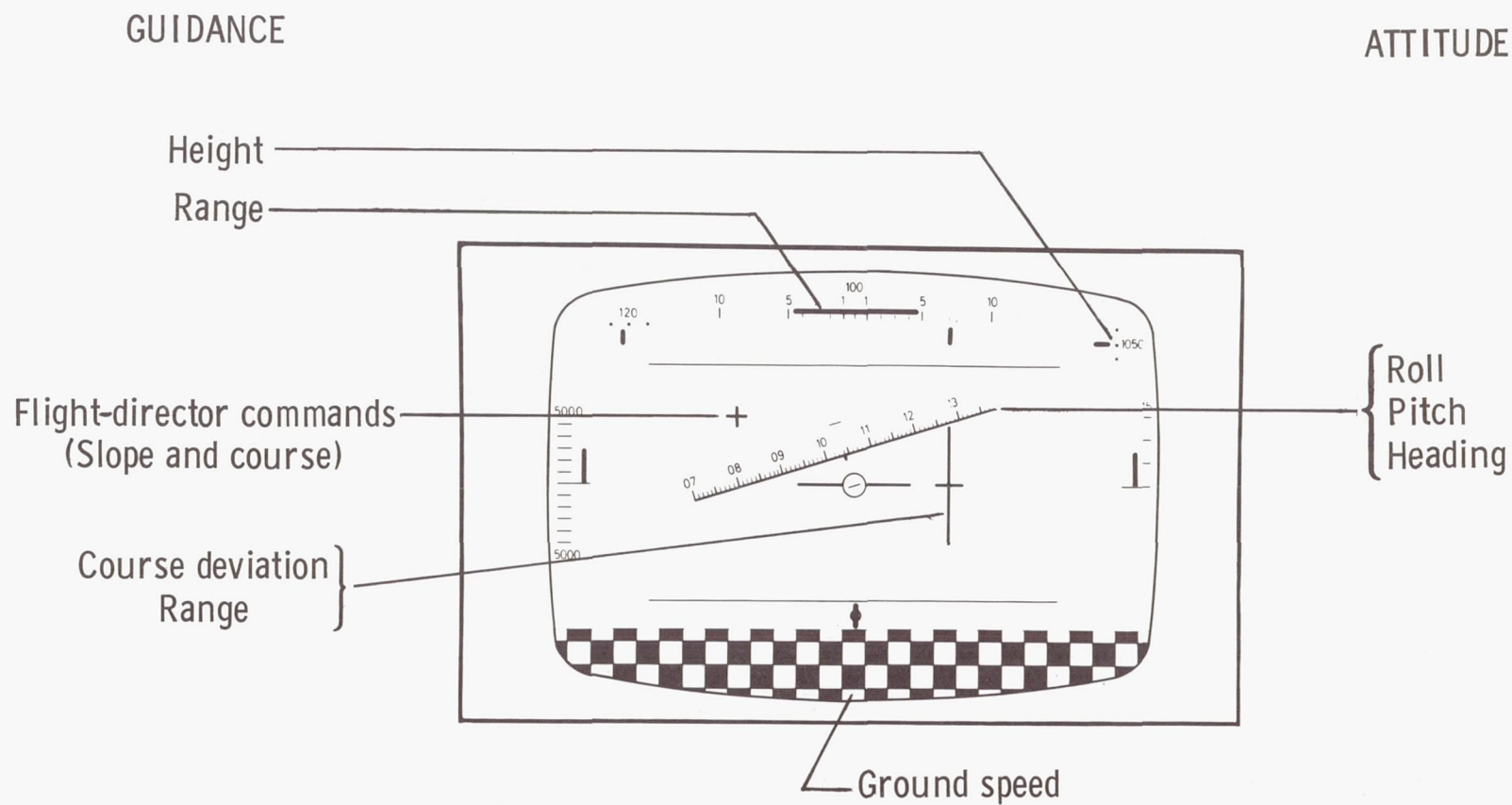
(a) Labeled.

Figure 10.- Display B-1.



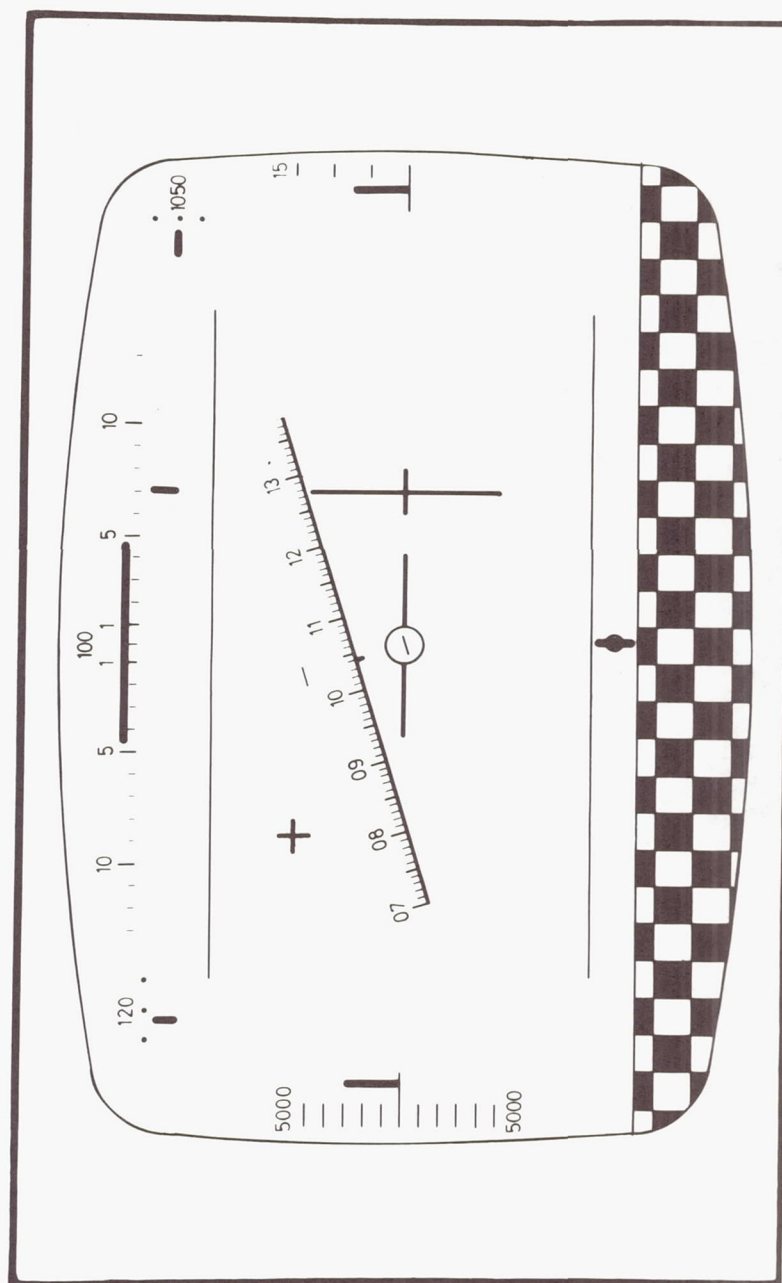
(b) Unlabeled.

Figure 10.- Concluded.



(a) Labeled.

Figure 11.- Display B-2. (This figure was supplied by the Institute for Flight Research, German Research Institute for Air and Space Travel.)

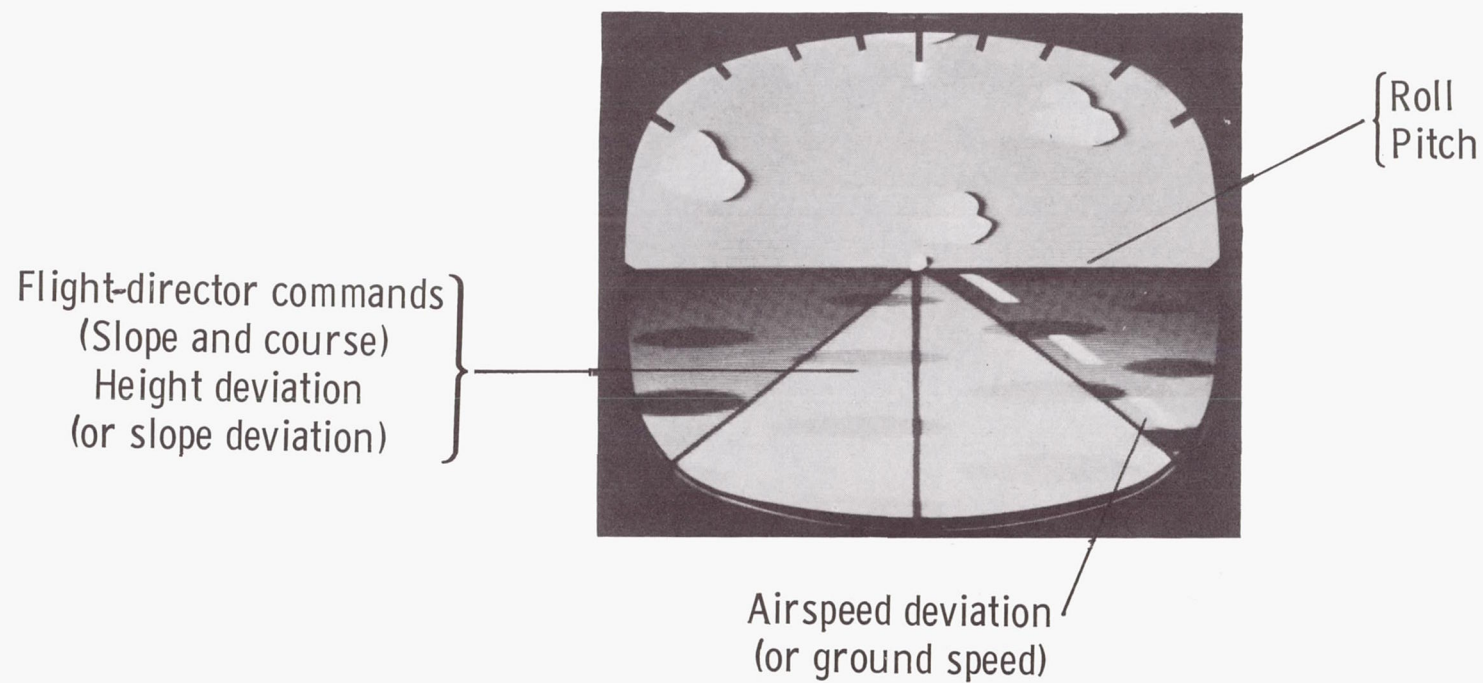


(b) Unlabeled.

Figure 11.- Concluded.

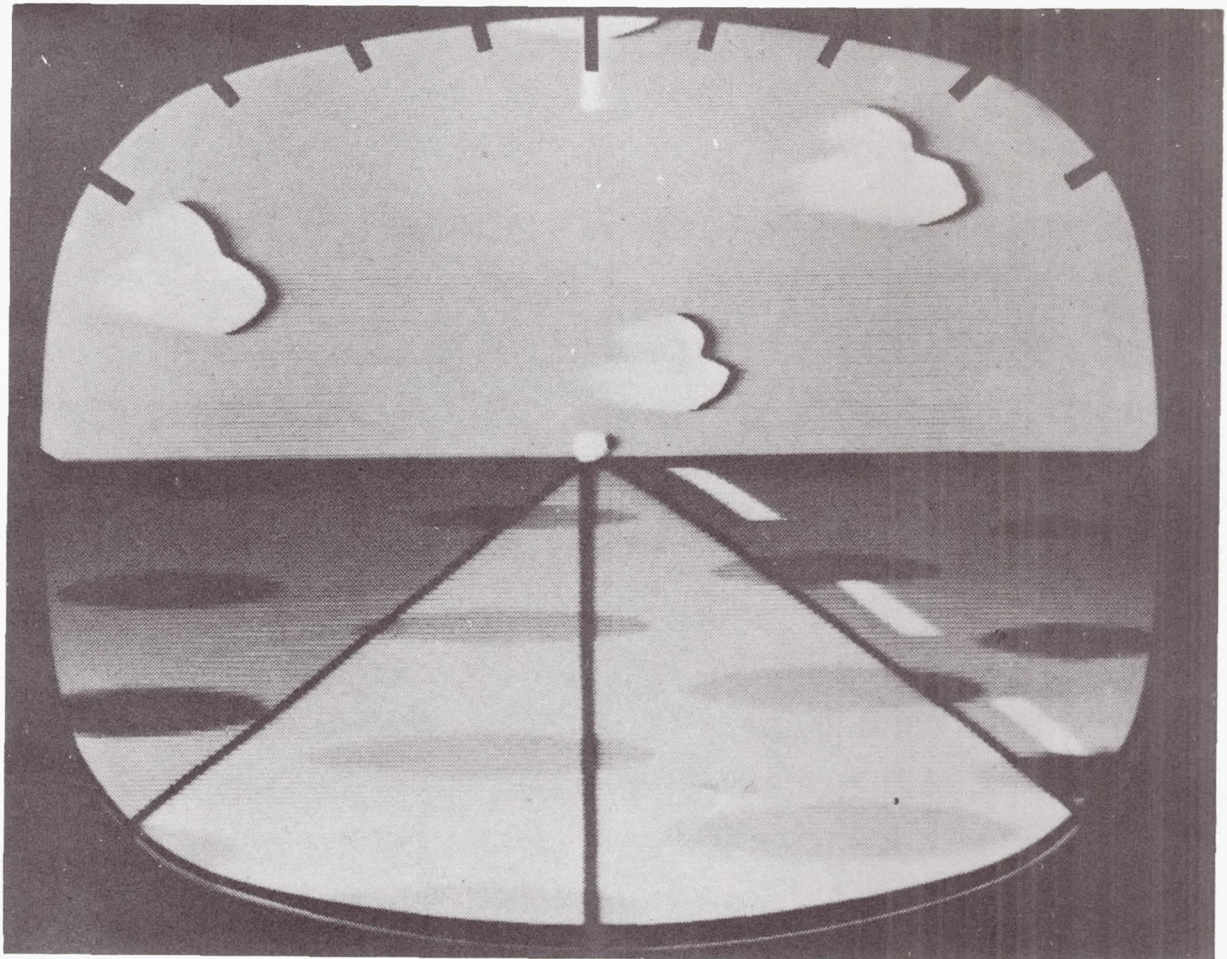
GUIDANCE

ATTITUDE



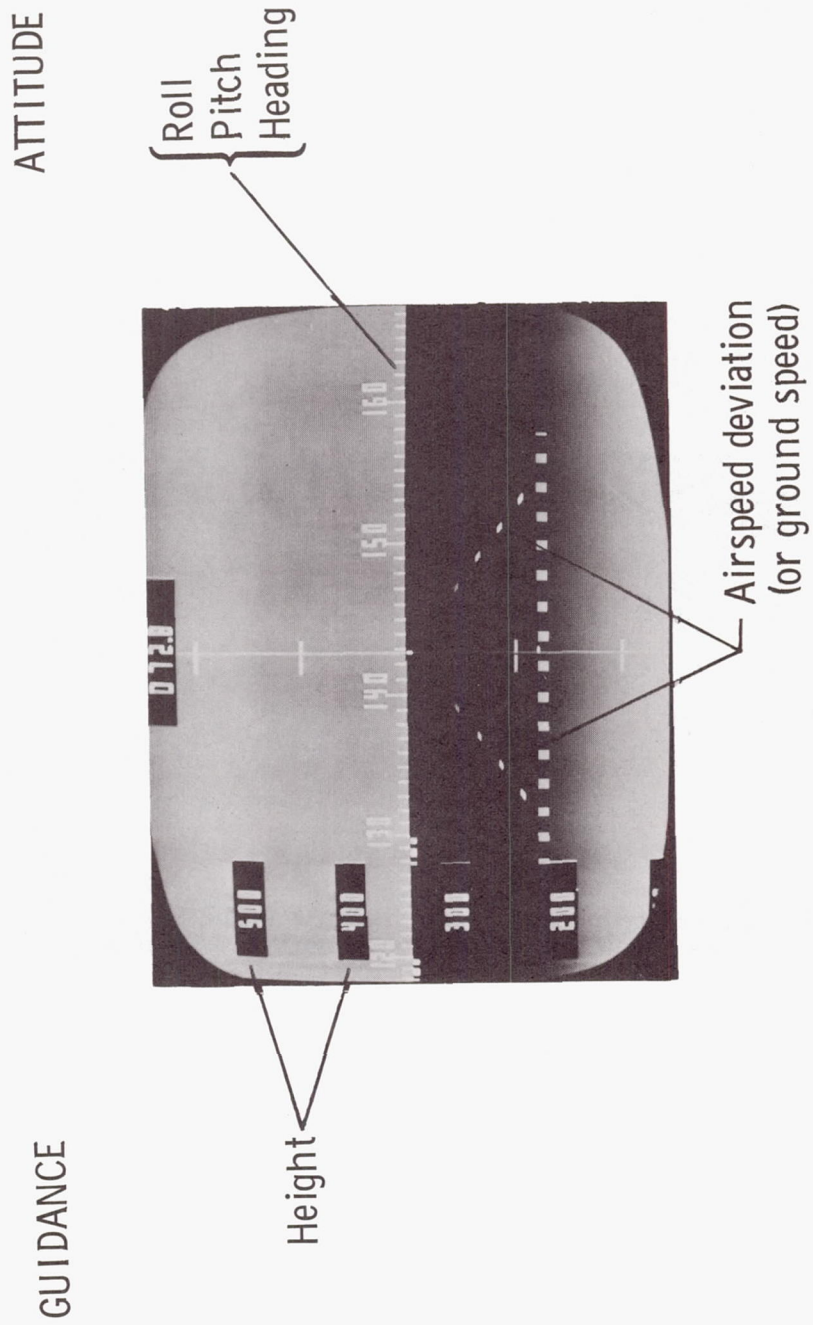
(a) Labeled.

Figure 12.- Display C-1.



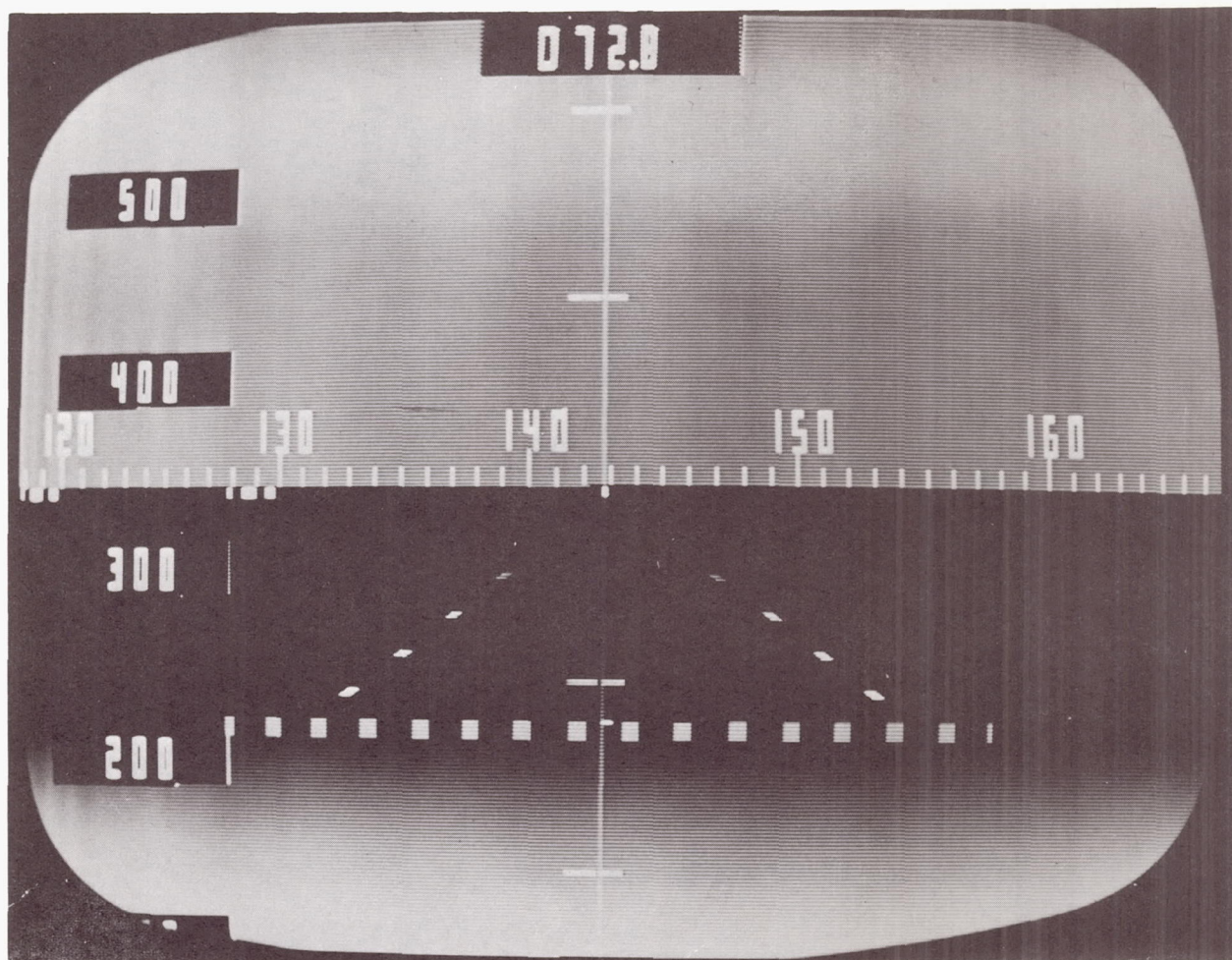
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Figure 12.- Concluded.



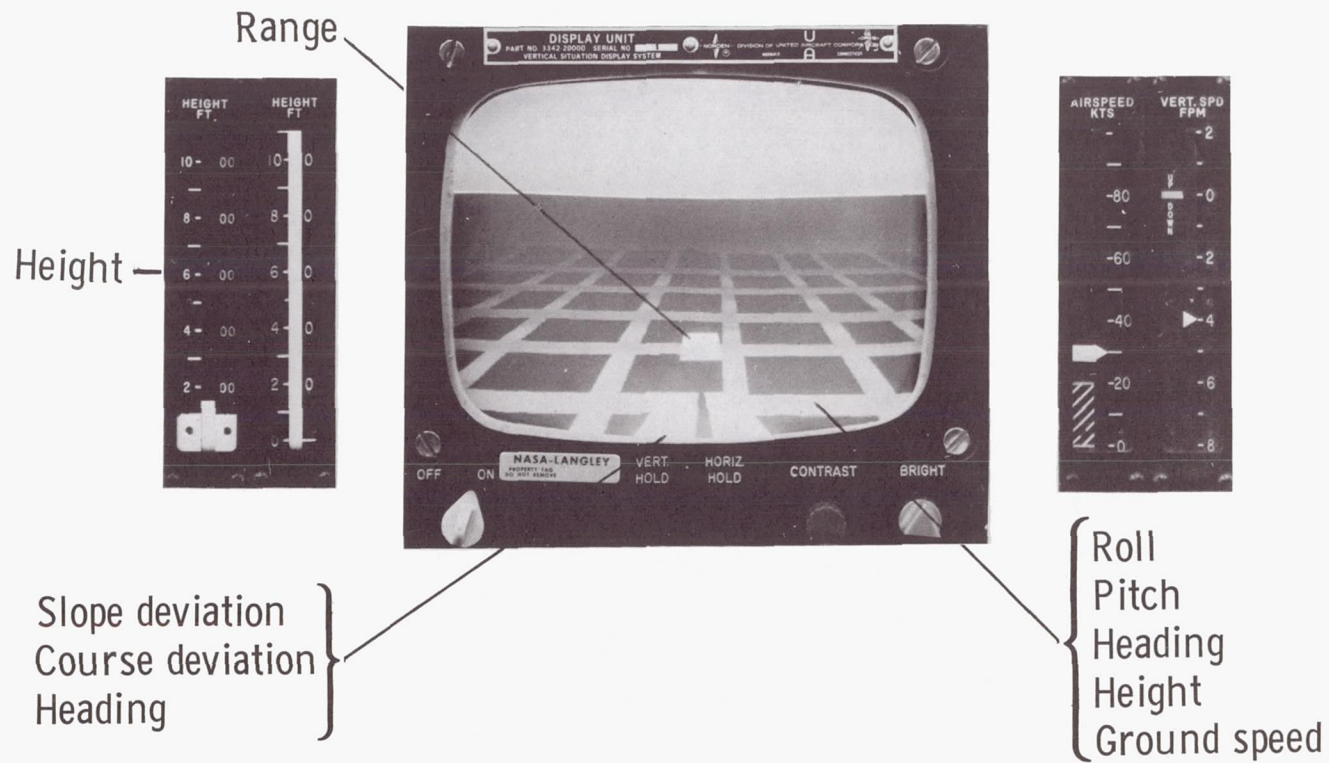
(a) Labeled.

Figure 13.- Display C-2.



(b) Unlabeled.

Figure 13.- Concluded.



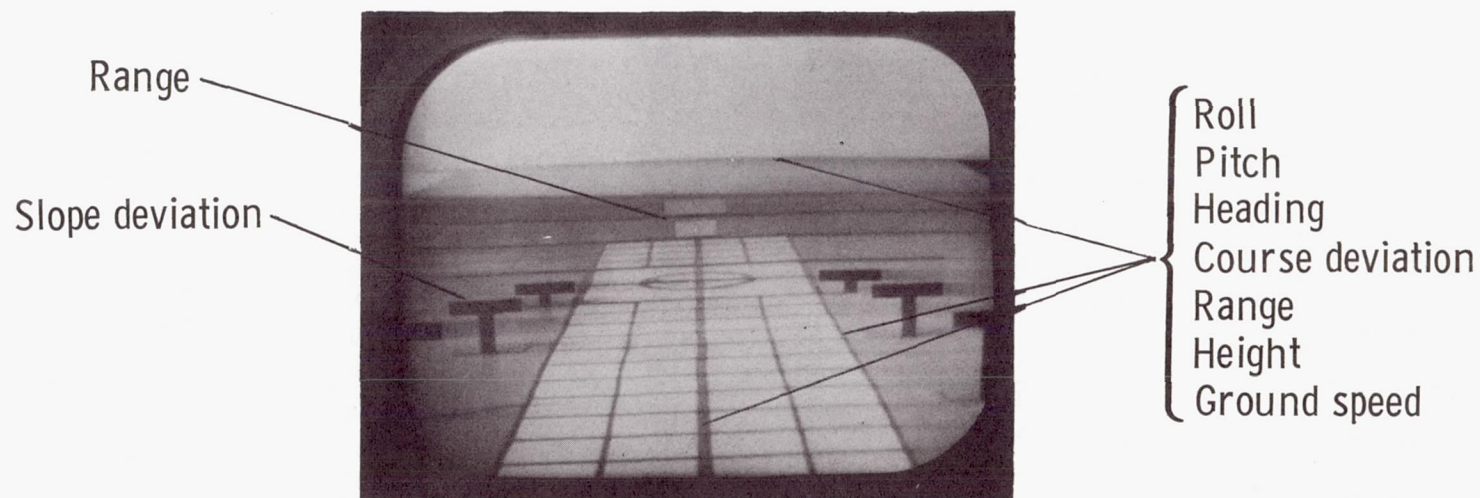
(a) Labeled.

Figure 14.- Display D-1.



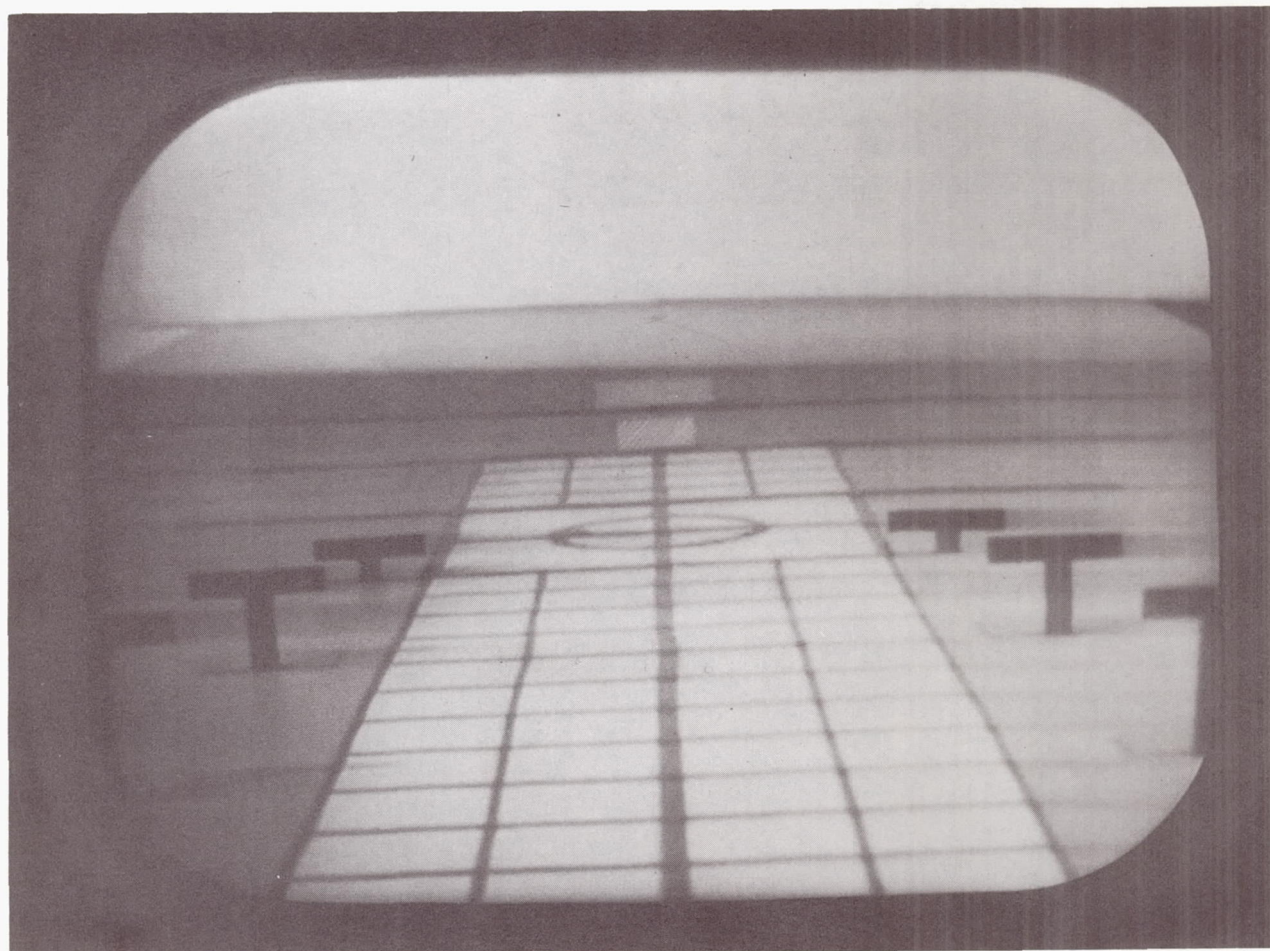
(b) Unlabeled.

Figure 14.- Concluded.



(a) Labeled.

Figure 15.- Display D-2.



(b) Unlabeled.

Figure 15.- Concluded.

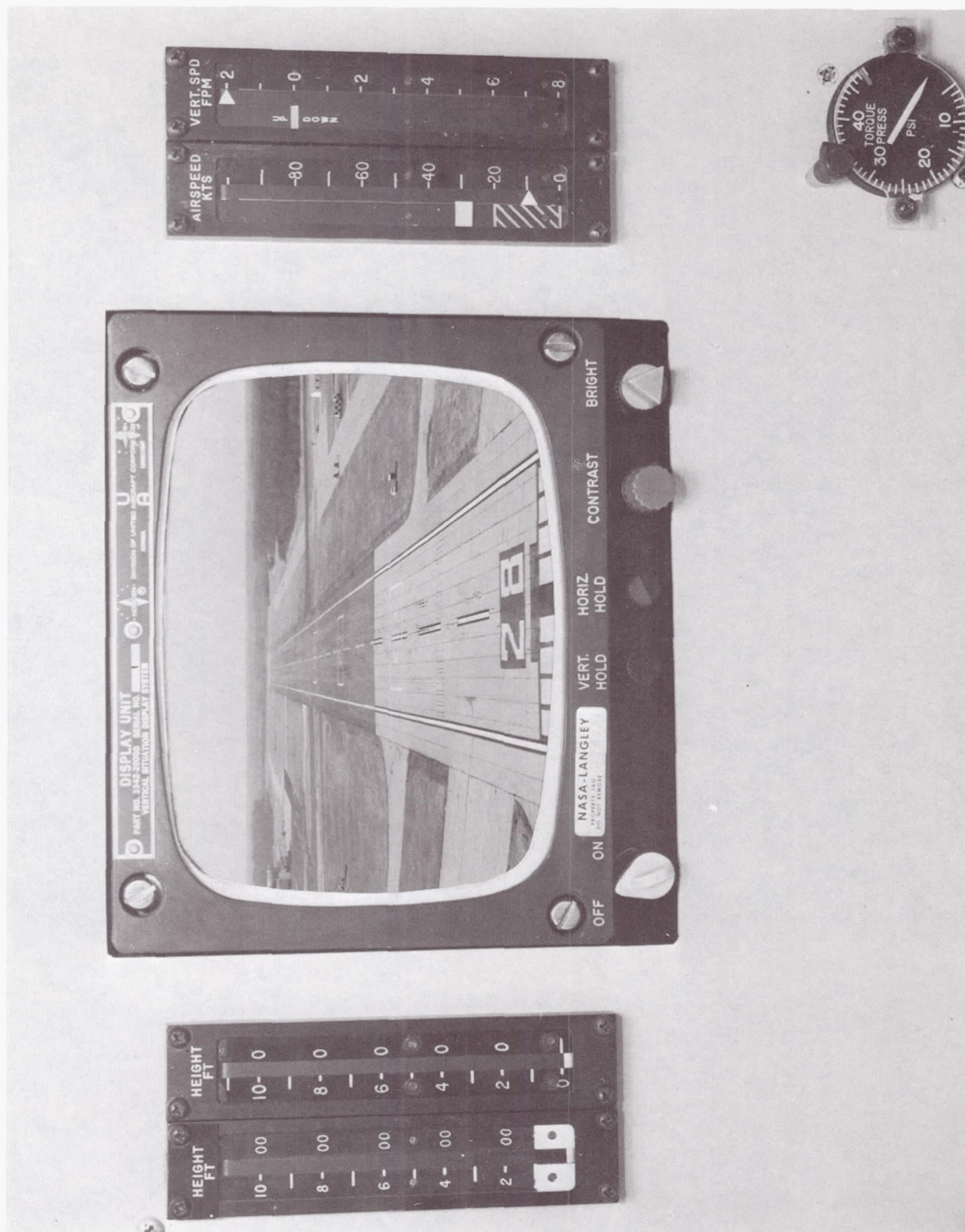


Figure 16.- Composite photograph of cockpit display and airfield used for tests of closed-circuit television display of reference 19.